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APPLICATION OF COLOR-COMBINED MULTIPLE POLARIZATION RADAR IMAGES TO GEOSCIENCE PROBLEMS*

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ABSTRACT

When a number of remote sensors are used in concert they give images no one of which need give a secure diagnosis, but together these images may lead to unmistakable identification of natural or cultural objects. In order to analyze a number of such images simultaneously (an exceedingly difficult task, if done manually), an Image Discrimination Enhancement Combination and Sampling (IDECS) System has been developed by Engineering personnel of the University of Kansas primarily to work with multifrequency, poly-polarization radar images. This paper briefly describes the operation of the system in producing color combined radar images on a color television set, in producing differentiated and other modes of image enhancement, and in deriving probability density functions from the images. Examples are given of the way in which color combined multiple polarization radar images improve discrimination of lithologies and crops over that of a single radar image. Finally, a number of future modifications intended for improved texture discrimination, and data space sampling are described briefly.

INTRODUCTION

During the last three years there has been a notable surge of interest in the use of remote sensors, especially those mounted on spacecraft, as a means for mapping and grappling with geoscience and resource-oriented problems. Much of this interest has been stimulated by feasibility studies conducted under contract to the National Aeronautics and Space Administration. Many studies have adopted as a working premise, the idea that when a number of remote sensors are used in concert, they give data no part of which is diagnostic, but which together may be unmistakable. This concept, for which R.N. Colwell (1961) uses the phrase "multiband spectral reconnaissance," underlies much of this research.

As a portion of the NASA-sponsored feasibility studies in the use of radar, in which we are engaged at the University of Kansas, Center for Research in Engineering Science (CRES), a number of papers have been produced using single frequency radars or, at the most, two black and white radar images of different polarizations obtained simultaneously. Dellwig and Moore (1966) and Morain and Simonett (1966) report on results of geologic and geographic interest using these black and white images and employing manual inspection of the images.

A number of universities and government agencies have jointly recommended on a preliminary basis to NASA that three radar wavelengths -- 3.7, 15 and 16 cms.-- appear to be technically feasible for spacecraft use. The concept behind simultaneous data acquisition with multi-frequency radars is that this would represent the microwave equivalent of multi-band spectral reconnaissance. The different information content of the three widely spread frequencies in the microwave region should give us much more secure identification of objects of geoscience interest than the use of a single frequency. The same kind of reasoning lies behind a parallel recommendation that multiple polarization data be obtained in each frequency. In each frequency three polarizations are involved and thus a matrix of nine combinations of frequency and polarization is possible. It will immediately be recognized that this presents a classic multi-discriminant problem which would be impossible for the unaided individual to handle effectively or even to comprehend a small portion.

When a single radar image is used, it has been our experience that instrumental aids to discrimination can be helpful in image interpretation and analysis. When two or more images need to be considered simultaneously it soon becomes apparent that the eye and the mind are unable to accommodate the complexities contained in two or more data-planes. Simple devices (such as change-detection systems which alternately present one image to the left eye and the other to the right eye) have proven inadequate to develop quantitative understanding of image differences, and it has been necessary to develop more flexible equipment. This paper describes some of the approaches we have developed at CRES particularly in the color

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combining of multipolarization radar images an an aid in discrimination and sampling of multiple images.

ATTRIBUTES NEEDED IN AN IMAGE PROCESSING SYSTEM

Ideally, an image processing system needs to be able to combine in various ways a number of images, to be able to use color as a means of aiding discrimination, to enhance selected areas or edges for improved identification or discrimination, and to be able to sample portions of the data for statistical and other manipulations.

In geologic terms for example, we are interested in being able to:

1. discriminate lineaments both natural and artificial and separate them from non-lineament background, in such a manner as to speed up discrimination of an operator over that of the manual use of several images.
2. improve identification and discrimination of lithologies and,
3. improve segregation of data into manageable sets and subsets which have meaning within a geologic reference scale
4. derive relations which we are unable to obtain manually because the mind cannot comprehend vector-space with two or three images
5. rapidly delineate anomalous details as a means for focusing energy on areas of geologic interest.

It is to be recognized that such an instrument may speed identification, but not necessarily, for if discrimination is improved, the additional information also needs to be processed.

The instrumental setup I propose now to describe is one of several developed under the direction of Dr. R. K. Moore of the Electrical Engineering Department, University of Kansas. This data handling system was designed specifically to enable geologists and geographers to cope with the differences in information content available in multiple frequency, poly-polarization radar images.

THE IDECS DATA HANDLING SYSTEM

The Image Discrimination Enhancement Combination and Sampling (IDECS) Data Handling System developed for geoscience research is illustrated in Figure 1. A systems diagram for the IDECS Data Handling System is given in Figure 2.

The first operation in the IDECS Data Handling System is the scanning of up to three images in a three-channel flying-spot scanner (FSS). The electrical analogs of images placed on the faces of the FSS are fed individually or collectively to a matrixing unit and the output of the matrix are

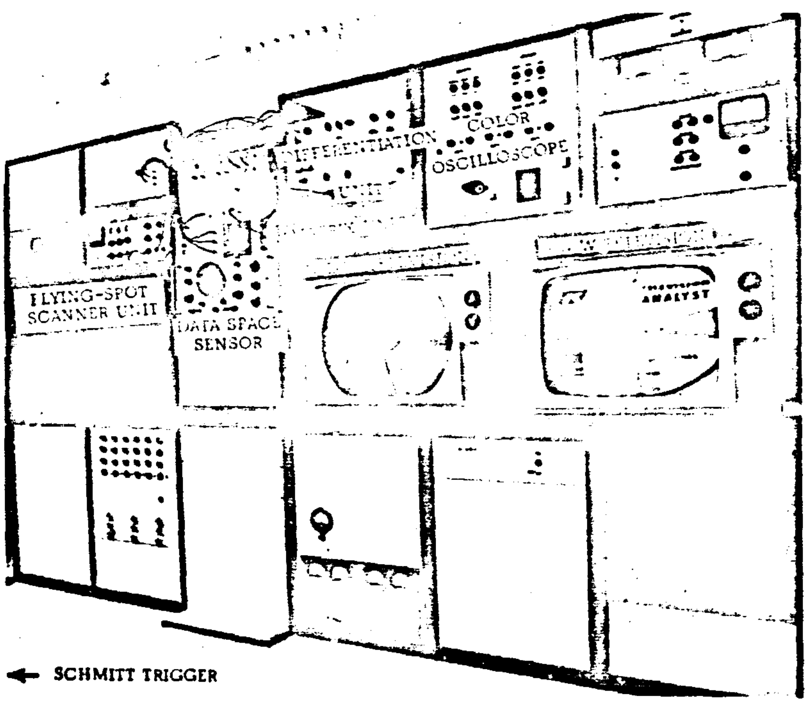

Figure 1.-The IDECS (Image Discrimination, Enhancement, Combination and Sampling) Data Handling System developed at the University of Kansas.

presented to the three (red, blue, and green) electron guns of the cathode ray tube in a color television (CTV). By this means, combinations of images can be reproduced in various colors to aid their geoscience interpretation. A black and white television (BWTV) is also used to present the output from any one of the red, blue or green channels from the matrix unit. Both the CTV and BWTV are synchronized with the FSS by synchronizing their rasters (see Figure 2). An alternative tri-color oscilloscope (TCO) may also take the outputs from the matrix or directly from the A, B, and C channels of the FSS. This device has very high color fidelity, but poorer resolution than the CTV. It may, however, be used for scanning images and handling radar scatterometer data. No further discussion of this unit will be given in this paper. The output of either the red, blue or green channels from the matrix unit or the A, B, C channels of the FSS may also be fed into a pulse-height analyzer to produce probability density functions and other statistical manipulations. The A, B, and C channels of the FSS may also be sampled with a data space sensor (DSS) or a Schmitt trigger and the outputs from these devices in turn may be fed to the CTV to selectively enhance the data sampled by the DSS and Schmitt trigger. Finally, a differentiation unit is included which enables one or more images to be differentiated and presented in different colors to the CTV. The detailed operation of each of these separate sections may now be described.

Flying-Spot Scanner

The present FSS is a three-channel instrument. Future modifications include the addition of further channels.

Matrix Unit

The matrix unit adds portions of three input signals from the FSS to form three output signals. The three outputs are produced by multiplying each input signal by a constant and summing the products. For example, signals x(t), y(t), z(t) are multiplied respectively by A_{11}, A_{21}, A_{31}, (where the first subscript denotes a row and the second subscript denotes a column) to give the output $x(t)A_{11} + y(t)A_{21} + z(t)A_{31}$. The second and third outputs are produced similarly with the summation over the second and third columns of constants. The matrix constants may be adjusted in discrete steps of 0.1 through the range $-1 \leqslant A_{mn} \geqslant 1$. The operation of the matrix unit can be represented mathematically by the multiplication of a 1x3 matrix by a 3x3 matrix. The prime use of the matrix unit is as an aid in interpretation of imagery by fractional overlaying of imagery. The procedure is to place congruent, multifrequency or multipolarization radar images on the faces of each of the three cathode ray tubes of the FSS. The outputs of the flying-spot

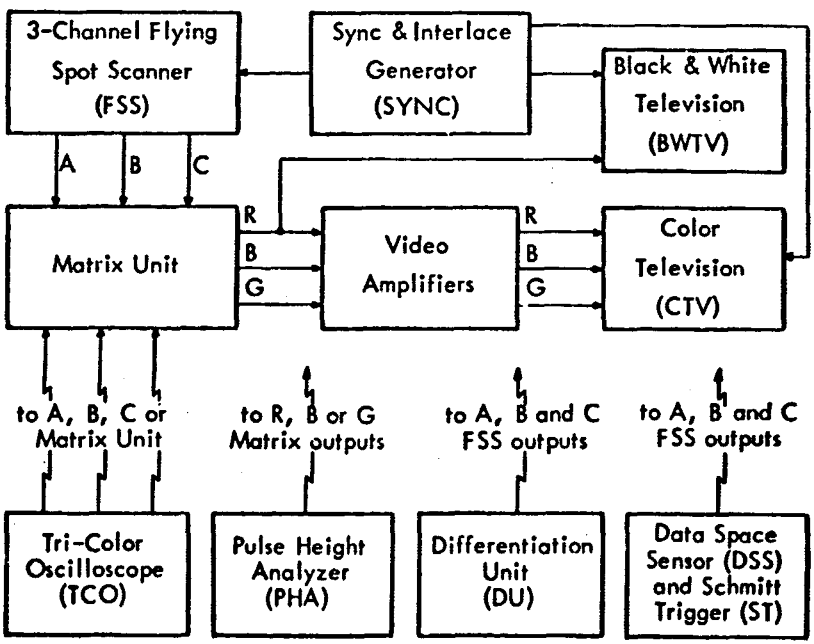

Figure 2.- Systems diagram of the IDECS data handling system.

scanner are then applied to the inputs of the matrix unit and the outputs of the matrix unit are connected to the video amplifiers of the CTV. Matrix constant switches are then set to obtain the desired enhancement of imagery. Because it is possible to adjust the polarity of the image, it becomes feasible to use three colors with a two-image display as well as three colors with a three-image display. Through using the polarity switches to give positive and negative images in the different colors it becomes possible to level-slice and clip out the upper or lower portions of an image.

Using this system it is also possible to mix a differentiated and unaltered signal, allowing many variations in the amount and degree of differentiated and unaltered signal to be applied to the CTV. A number of color images obtained with this system are presented and discussed in the oral presentation of this paper. However, for purposes of reproduction it has been possible to use only black and white illustrations.

Differentiation Unit

It is often difficult to determine the rate of density change in multiple radar images either in black and white or in color reproduction. The density change can be abrupt or gradual depending on the rate of variation of radar scattering parameters of the area being examined. Color combination tends to point out some density differences, but this is often not emphatic enough for rapid evaluation. Also, for some combined images, some of the subtle differences at points of abrupt density changes are not immediately evident.

To overcome some of these problems, a differentiation unit has been devised for edge enhancement. This unit consists of three independent differentiation circuits. On each circuit the time constant can be adjusted over a wide range thereby detecting lines of different widths. The circuit is modified so that both positive and negative derivitives give a positive outpur. By using three independent differentiating circuits we can simultaneously enhance three input photographs in contrasting colors on the CTV. Also, it is possible to hook the derivitive circuits in sequence so that we can take multiple derivitives of the same signal.

Data Space Sensor

The data space sensor (DSS) allows the operator to arbitrarily choose a certain joint photographic density value from two images and these points can be indicated by an enhancement of an image presentation. It measures the value of joint probability density functions at particular points for a two image system. Figure 3 shows an oscilloscope trace of the trajectories due to simultaneously scanning two photographs and presenting these on an oscilloscope. The length of time the trajectory is in a small area on the oscilloscope is proportional to the probability that the joint photographic density is within the values defined by the small area. The DSS consists of a fiber optics rod which is physically held over the face of the oscilloscope. The area sampled is defined by the cross-sectional area of the rod and the magnification of the two-dimensional trajectory densities on the face of the oscilloscope. A photomultiplier tube connected to the rod has an output whenever the trajectory is in the sampled area. Since the output of the photomultiplier is proportional to the time spent in the sampled data space it measures the joint probability. The unique application of the DSS makes use of the fact that the output of the photomultiplier is obtained synchronously with the presentation of information in a flying-spot scanner system. This output, therefore, can be used to emphasize or enhance in a special color the image that is being presented at a particular time on the CTV.

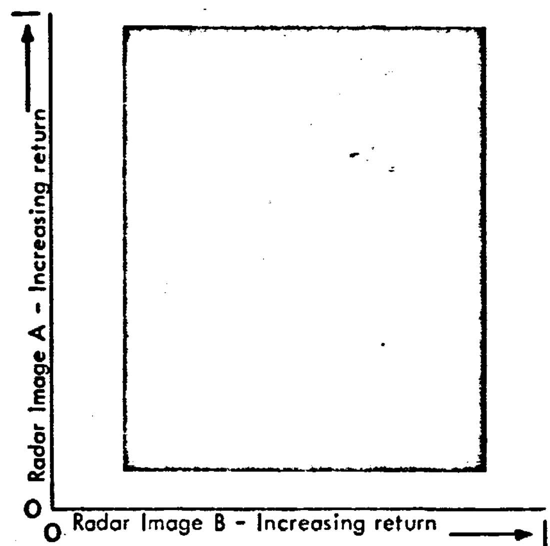

Figure 3.- Joint-probability density plot produced by scanning two radar images simultaneously.

Schmitt Trigger

The Schmitt Trigger (ST) is a device which can select any position in the dynamic range of a single radar image for selective enhancement on the CTV in color. All areas with values above or below that selected are assigned one color. Each of a number of images can be scanned in turn clipping at the same level so that later comparisons may be made.

Because the ST clips at a finite level certain areas (say lithologies) may be displayed as solid color on the CTV if all components of the probability density function of the area (lithology) lie above or below the selected clipping level. In other cases, areas which cannot be distinguished from one another on the basis of average gray scale (such as would be obtained with a microdensitometer trace) may be discriminated because the skirts of the probability density function of one natural object may lap across the zone where the ST is clipping while another may not. It therefore becomes possible to discriminate between two closely similar regions on the basis of the degree to which they acquire a speckled character on the CTV arising from the presence of small numbers of high intensity returns or low intensity returns, as the case may be. It becomes apparent, then, that the ST is a device which samples in a broader area of data space than the DSS unit, but that at the same time it may add to our ability to discriminate. At the time of the writing of this paper only one Schmitt Trigger was in operation. By the time of the symposium, however, we will have Schmitt Triggers which can slice in such a manner as to produce oblongs or squares in data space. Figures 4 and 5 may be compared to see the nature of the color combinations and enhancement possible.

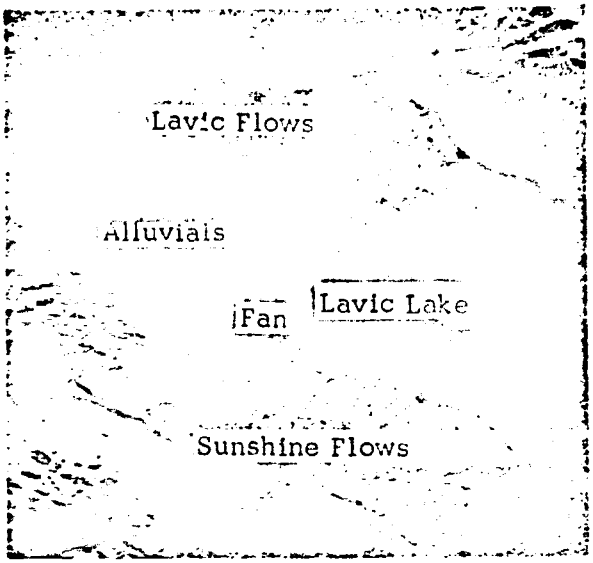

Figure 4.-K-band radar image of Pisgah Crater Area, California.

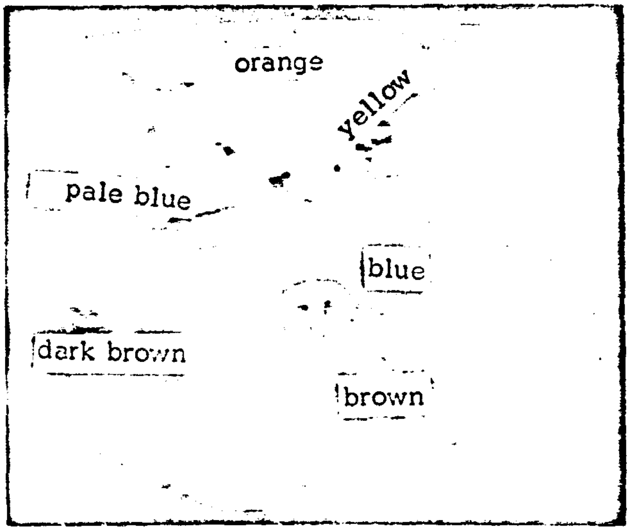

Figure 5.-Color combined and enhanced radar image to indicate improved lithologic discrimination.

FUTURE CAPABILITIES

The IDECS system as now operative gives some textural discrimination. However, this is not specifically a portion of the d sign, but arises incidentally from operation of the Schmitt Trigger and Data Space Sensor. A modification to the system is planned which will enable both improved texture discrimination and measurement of accutance This will be achieved by changing the sweep in the flying spot scanner to give various modes of spiral and circular trajectories.

Another technique of potentially great discriminant power is now under development, which will represent a significant expansion of capabilities of the Data Space Sensor and Schmitt Trigger. This device, for which both the theory and circuit design have been completed, is intended to sample in n-space and produce a binary color-coded output in the form of a color coded image. On this image discrete classes should be distinguishable. This latter development forms the basis for Mr. Dalke's presentation at this colloquium and is described in detail by him.

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